



Reducing Intervention in the COVID-19 Era: Opportunities for Vital Pulp Treatment

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Over the last 12 months, the Severe Acute Respiratory Syndrome Coronavirus 2 (SARS-CoV-2) virus has emerged as a significant global health problem with extensive repercussions for the practise of dentistry. As the principle transmission-route is via droplet-spread, aerosol-generating dental procedures (AGPs) present an exquisite challenge, which either has to be avoided or performed using strict infection-control measures, which increase the deployment of resources and cost. This new working environment necessitates the adoption of simplified, yet effective procedures that reduce intervention and minimise clinical chair time to short, single visits. Vital pulp treatment (VPT) has emerged as an attractive, technically less-complicated group of biologically-based management strategies that are aimed at maintaining pulp vitality and avoiding root canal treatment (RCT). These procedures are carried out in a strict aseptic environment using a rubber dam and have a reported high success rate, suggesting that they could be considered as effective and simple alternative therapies to relieve pain and avoid multiple visit RCT and other endodontic procedures. The relevance of promoting a simple, predictable and effective alternative to traditional, more complex dentistry has never been more compelling. In this perspective article, the latest advances in VPT are highlighted, along with an analysis of their relative success and compelling reasons why we as dentists should be adopting these treatment approaches. Thereafter, case selection, prognostic factors, techniques, limitations and future prospects of these procedures are discussed.

Keywords: VPT, pulpitis, irreversible pulpitis, vital pulp therapy, endodontics

INTRODUCTION

Since the advent of the novel coronavirus (SARS-CoV-2, COVID-19) at the end of 2019 and subsequent global spread, the fields of Medicine and Dentistry have been thrust into an uncertain and rapidly evolving new normality. Within Dentistry specifically, there has been a focus on the generation of aerosols, so called aerosol-generating procedures (AGPs), as well as concerns relating to the length of patient appointments, emergency-only treatment and reducing the invasiveness of treatment. Endodontics has been forced to deal with this situation more than most areas of Dentistry, as Endodontic procedures invariably require the use of high-speed handpieces, deal with patients in acute pain whose treatment cannot be deferred and carry out invasive time-consuming

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treatments. As a result, groups like the European Society of Endodontology (ESE) (<https://www.e-s-e.eu/index.html>), American Association of Endodontists (AAE) (<https://www.aae.org/specialty/clinical-resources/covid-19-updates-resources/>) and the British Endodontic Society (BES) (<https://britishendodonticsociety.org.uk/>) have regularly updated their websites with bulletins of the latest advice for Endodontists, General Dentists and patients on how to limit viral load during endodontic procedures.

COVID-19 is characterised by its ability to transmit from individuals who asymptomatic, through multiple transmission pathways, including respiratory droplets, skin contact, aerosol-borne and faecal-oral routes. This has created uncertainty with regard to prolonged dental procedures, particularly aerosol-generating procedures (AGPs), which are unavoidable during endodontic therapy. As a result, strategies to reduce contact time and complexity such as vital pulp treatment (VPT) (1) have been highlighted and promoted as a way of reducing the potential of virus spread and increasing simplicity. VPT has recently been advocated as a treatment not only for exposure of the pulp in cases without symptoms and reversible pulpitis (2) but also in the management of cases with more severe damage and irreversible pulpitis (3, 4). There is an increasing scope for minimally-invasive therapies such as VPT to reduce intervention and indirectly reduce aerosol in endodontics as a result the aim of this perspective article is to make a case for the promotion of VPT over traditional root canal treatment (RCT) in cases even with a diagnosis of irreversible pulpitis.

PERSPECTIVE AND DISCUSSION

The recent promotion of regenerative endodontic techniques and the clinical development of minimally-invasive VPT presents an exciting clinical focus for the dental profession. In these biologically-based procedures, the biology of the pulp and surrounding tissues is exploited to optimise the healing following injury (5). Although, within the remit of all dentists VPT requires an understanding of the biological processes taking place if they are to achieve maximal clinical impact. In this perspective article, we highlight some of the key processes upon which clinical attention should be directed as well as considering ways in which the reparative events in the pulp-dentine-pulp complex can be maximised.

What Are Biologically-Based Therapies and VPT?

VPT can be defined as a range of therapeutic strategies aimed at maintaining the health of all or part of the pulp (2). These strategies include techniques to preserve pulp vitality in teeth with deep caries by avoiding pulp exposure (e.g., selective caries removal, indirect pulp capping) (6) or conservative management of the exposed pulp (e.g., pulp capping, pulpotomy) (7). At the core of VPT is the stimulation of the dentine-pulp complex's healing capacity, thereby defining VPT as a range of minimally invasive biologically-based wound healing strategies aimed at pulp regeneration processes (5). When considering the

promotion of VPT it is critical that as clinicians we understand the nature of pulpal defence and healing, which generally involves a combination of pulpitis and reactive mineralisation in response to bacterial challenge (8, 9). In response to microbial irritation, initially, the odontoblasts and later fibroblasts, stem cells and immune cells mount a series of localised inflammatory responses (10). If uncontrolled this will lead to progressively increased pulpitis, which if unchecked can lead to pulp necrosis (11); however, if the stimulus is removed pupal healing is possible (12). If the pulpitis is allowed to continue intervention such as RCT or extraction will be required. These techniques may be unnecessary and remove tissue that could have been maintained had earlier intervention been carried out. This presents an opportunity for VPT to reverse or shift the balance of the disease toward a conservative repair of the pulpal injury.

Hard tissue repair involves the production of tertiary dentine, which forms alongside inflammation beneath the area of challenge (13). There are two types of tertiary dentine depending on the severity of the irritation. Reactionary dentine is formed after mild irritation and an up-regulation of odontoblast activity, while reparative dentine is formed in response to stronger stimuli and odontoblast death. Reparative dentine formation is complex processes involving the recruitment of dental progenitor cells and their subsequent differentiation into secretory odontoblast-like cells (13). The wound healing events are regulated by the release of dentine-bound bioactive molecules, which includes growth factors (GFs) and chemokines sequestered after damage to the dentine structure (14, 15).

After pulp exposure, a positive sign of healing is the formation of a reparative dentine hard tissue bridge (16), which helps to protect the pulp tissue from further damage. However, from a clinical perspective, the hard tissue may not be visible radiographically (17) and the outcome will be evaluated by clinical exam, history, sensibility tests and radiographs (2).

How Successful Are VPTs and What Determines Success?

The aim of the inflammatory process in the dental pulp is to clear the infection and initiate healing (18). The deep caries lesion (lesion extend to the inner quarter of dentine, but with a zone of hard or firm dentine between caries and the pulp) in which the pulp is not pathologically exposed, bacterial by-products diffuse through the dentinal tubules to initiate a protective inflammatory response that present clinically with mild symptoms mainly in response to thermal stimuli. In this situation removal of infected dentin using selective caries removal approach and sealing the pulp with restoration (indirect pulp capping), will ensure control of inflammation and maintenance of pulp vitality (2). In such teeth, the risk of pulp exposure should be avoided, but if ultimate, then direct pulp capping procedures has proved successful particularly when using calcium silicate cements (CSCs) (19, 20). However, in situations where caries is extremely deep (lesion penetrates the entire thickness of the dentine) bacteria gain access to the pulp space and here the inflammatory process takes another dimension, the severity and extent of which are determined by the level of bacterial contamination and the

pulp defence capabilities. Inflammation within the dental pulp usually commences at the site of bacterial entry, and spreads circumferentially from one compartment to another (21, 22), creating different histopathological diagnosis in various parts of the same pulp (23, 24). Therefore, making a single diagnosis for the entire pulp in such cases is theoretically incorrect. Currently, such teeth are diagnosed with irreversible pulpitis indicating that the pulp lacks the capacity to heal and therefore require pulpectomy and RCT (25). This implies that the total pulp (coronal and radicular) is damaged beyond repair. However, evidence from clinical research suggests that such teeth can be successfully treated by removing the diseased and leaving the healthy part of the pulp with pulpotomy procedures. Pulpotomy, whether partial or complete has many advantages over RCT; it is not only less technically demanding, but most importantly by retaining vital pulp tissue, protect the tooth from infections and apical periodontitis (26). A high success rate for complete pulpotomy has been shown for teeth with deep caries and exposed pulp (27, 28). Even when the diagnosis is symptomatic irreversible pulpitis, complete pulpotomy has a high clinical (97, 93%) and radiographic (95, 88%) success rate at 1 and 3 years, respectively (29). Similarly, partial pulpotomy has a high success rate of 98% at 1 year and 96% at 2 years of follow up in cariously-exposed pulp (30). The success rate for pulpotomy reported in these studies is comparable with that of root canal treatment of the vital pulp (31).

Many factors contribute to the outcome of VPT, but pulpal diagnosis is by far the most important determinant of the success of these treatments. Unfortunately, the current subjective pulpal diagnostic methods do not faithfully reflect or quantify the degree of pulp inflammation (32), and it is, therefore, likely that reported failures are associated with teeth in which inflammation is more extensive than predicted using these methods. Preoperative pain was suggested as a prognostic factor for pulpotomy (33), but high success has been reported for teeth with spontaneous lingering pain associated with symptomatic irreversible pulpitis (29). These contradicting findings only add to the limitations of our current diagnostic systems and suggest the need for a biomarker-based approach to pulpal diagnosis. The recent use of MMP9 as prognostic markers for pulpotomy outcomes (34), is a step in the right direction.

There are no known patient-related factors that are likely to affect the outcomes of VPT. The root maturity has however been shown to affect direct pulp capping (35) but not the pulpotomy. The choice of the capping material is also important. The introduction of the CSCs has contributed greatly to the success of VPT (16) and its use is recommended by ESE (2). When performing VPT for the cariously-exposed pulp, clinicians often have to deal with pulp exposure that happens through a zone of bacterial contamination. It has been suggested in this case that an enhanced operative protocol including aseptic procedure, use of magnification and disinfectant is important (2). Clinicians may consider using a rubber dam for optimal isolation and use sodium hypochlorite to wash and disinfect the pulpal wound (36).

Although high success rates have been reported for VPT, the evidence from these studies has to be interpreted with caution. Many of the interventional studies conducted are single-arm

studies (case-series), which by definition are not controlled. As a result, there remains an unmet need for high-quality, adequately-powered and well-conducted randomised controlled trials to evaluate different VPT strategies both against root canal treatment and to other VPT techniques. An evaluation of the recent systematic reviews reporting on the outcomes of different VPT modalities demonstrated that the methodological quality of most of the reviews is low (Table 1), and this has mainly been attributed to either a limited number of included studies or the absence of a meta-analysis due to heterogeneity in study designs and outcomes. Future studies investigating VPT should be prospective, comparative studies using developed core outcome sets that facilitate evidence synthesis and guideline development (38).

What Is Feasible and What Are the Limitations of VPT?

Despite development in VPT biomaterials, the problem with the current diagnosis system is a major barrier to the successful development of minimally invasive biologically based therapies. When treating teeth with deep caries and diagnosis of reversible pulpitis and pulp exposure can be avoided, using stepwise excavation and indirect pulp capping is a strongly recommended approach (2). The main clinical dilemma is when the pulp is exposed during caries removal and whether practitioners should do direct pulp capping, pulpotomy or RCT? The emerging evidence suggests that in teeth with deep caries and exposed pulp, but with signs and symptoms indicative of reversible pulpitis attempts should be made to adopt a more conservative approach such as direct pulp capping using CSCs (19). Isolation is important and the provision of a good coronal seal is essential. However, for teeth with exposed pulp and signs and symptoms suggestive of irreversible pulpitis, a pulpotomy (partial or complete) should be attempted (29). In either case, the degree of pulpal inflammation is unknown, but pulpal bleeding is traditionally been used as an indicator of the severity of inflammation (39). Earlier studies demonstrated generally high success for direct pulp capping of cariously exposed pulp when bleeding is slight and can be controlled within 30 s (39). However, recent studies in which CSCs were used as capping material, a high success of DPC was reported when bleeding can be controlled within 5 min (40). Even in cases diagnosed with irreversible pulpitis studies reported control of bleeding within 6 min in over 80% of cases during partial or complete pulpotomy (3, 41). Therefore, bleeding time may not be as critical as originally reported and the ESE position statement recommended bleeding to be controlled with cotton pellet soaked in sodium hypochlorite (0.5–5%) for up to 5 min (2). There are currently no validated clinical protocols for VPT, but the evidence from emerging studies and the ESE position statement on the management of deep caries and exposed pulp (2), suggests the adoption of a conservative approach to maintain pulp vitality as possible (Figure 1). Although not advocated at present, some research reports suggest successful direct pulp capping for teeth with irreversible pulpitis (1). In the authors' opinion, the dental pulp in a tooth with symptomatic irreversible pulpitis is likely

TABLE 1 | Summary of evidence from recent systematic reviews on VPT studies on permanent teeth assessed using AMSTAR-2 (37).

HP study	VPT modality	Pulpal diagnosis/status	Outcomes and conclusions	AMSTAR-2 rating
Cushley et al. (19)	DPC	Cariously exposed pulp with RP	Calcium hydroxide success rate was 74% at 6-months, 65% at 1-year, 59% at 2–3 years and 56% at 4–5 years. MTA success was 91, 86, 84, and 81% at the same time points. Biodentine success was 96% at 6-months, 86% at 1 year and 86% at 2–3 years. The meta-analysis revealed MTA had better success than calcium hydroxide at 1 year OR = 2.66 (95% CI; 1.46–4.84, $P = 0.001$) and 2- to 3-year follow-up OR = 2.21, (95% CI; 1.42–3.44) $P = 0.0004$, but no difference between MTA and Biodentine.	High quality
Paula et al. (20)	DPC and PP	Pulpal diagnosis not specified. Included carious and non-carious exposures	MTA had a significantly higher success rate, in all parameters, compared with calcium hydroxide cements (odds ratio = 2.72; 95% CI 1.90–3.90; $P = 0.000$), and success was not different when compared with the CSCs. Adhesive systems showed a significantly lower success rate compared with calcium hydroxide cements (odds ratio = 0.062; 95% CI = 0.024–0.157; $P = 0.000$).	Low quality
Alqaderi et al. (27)	CP	Cariously exposed pulp, mixed RP and IRP	The 1- and 2-year pulpotomy success were 94% (95% CI: 90, 99) and 92% (CI: 84, 100), respectively. Differences in pulp capping and restoration materials did not significantly affect success rates	Moderate quality
Li et al. (28)	CP	Cariously exposure mixed RP and IRP	Meta-analysis of data comparing MTA and calcium hydroxide in pulpotomy for immature and mature permanent teeth showed MTA had higher clinical success rates 12 months, OR = 2.23 (95% CI, 1.16–4.29), $P = 0.02$, $I^2 = 0\%$ and higher overall and radiographic success rates at 24 months OR = 2.20 (95% CI, 1.15–4.20) $P = 0.02$, $I^2 = 47\%$	Moderate quality
Cushley et al. (29)	CP	Symptomatic IRP	The average success rate for coronal pulpotomy was 97.4% clinical and 95.4% radiographic at 12-month follow-up. This was reduced to 93.97% clinical and 88.39% radiographic success at 36 months follow-up. Results from the only comparative clinical trial showed pulpotomy to have comparable success to root canal treatment at 12, 24, and 60-month follow-up	Low quality
Elmsmari et al. (30)	PP	Cariously exposed pulp, mixed RP and IRP	Partial pulpotomy has success rate of 98% (CI: 0.94–1), 96% (CI: 0.92–0.99), and 92% (CI: 0.83–0.97) after 6 months and 1 and 2 years follow-up. Preoperative pulp status significantly affects the success ($P = 0.001$), but final restoration, pulp capping material, apex closure, and the age of the patient does not affect success rate ($P > 0.05$).	Moderate quality

AMSTAR, a measurement tool to assess systematic reviews; DPC, direct pulp capping; CP, complete pulpotomy; PP, partial pulpotomy; RP, reversible pulpitis; IRP, irreversible pulpitis.

to be heavily contaminated with bacteria and to contain micro-abscesses, therefore, at least when using current biomaterials, surgical excision with partial or complete coronal pulpotomy will ensure remaining pulp tissue is healthier to recover and heal following treatment.

The success of VPT is often considered based on short- and long-term outcomes. The pain relief and maintenance of pulpal and periapical health are the main outcomes often evaluated in VPT. Failure is generally considered to occur early (within 6 weeks of treatment) (33, 42). Most of the early failures are related to persistent pain and symptoms of irreversible which reflects issues with diagnosis as discussed earlier. Late failures include pulp necrosis and periapical infections and all these can be successfully managed with RCT. So, here VPT provides the opportunity to delay complex interventions like RCT and contribute to improving the life cycle of the tooth. However, optimal clinical protocols and case selection for VPT require the development of more reliable methods and better classification for pulpal diagnosis (43). Until such become available, clinician may utilise their expertise guided with the current available evidence to apply VPT in their clinical practise. Application

of these therapies has numerous advantages over conventional RCT in terms of pain relief, tooth survival, aerosol-generation, time and costs as outlined in **Table 2**. These advantages are of particular importance at a time where both dentists and endodontists are developing strategies to reduce chair time in order to minimise viral load.

Future Perspective

The regenerative capacity and healing ability of the dental pulp is well-known, but our current clinical practise in managing the cariously exposed pulp didn't reflect this knowledge. The emerging evidence on the success of VPT needs to be consolidated with more clinical research as well as translational research to address many unmet needs. The current pulp diagnosis methods are not fit for purpose and there is a need for molecular tests to accurately diagnosis pulp status and predict treatment outcomes. The existing pulp diagnosis classification (reversible/irreversible) is also not permissive of minimally invasive treatments and with the success reported for VPT in cases of irreversible pulpitis, such classification became irrelevant. There is also a need for biomaterial development

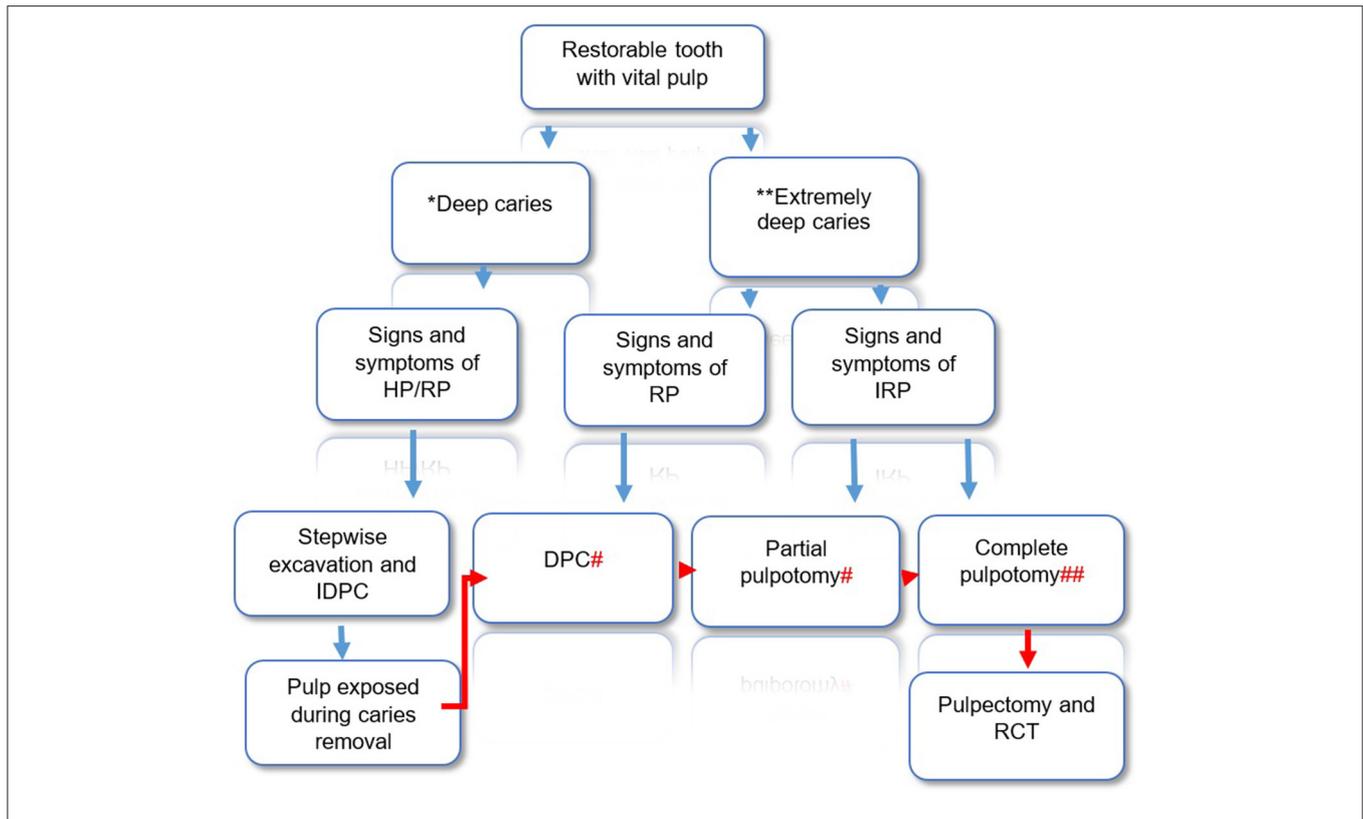


FIGURE 1 | Decision making for VPT in restorable teeth with deep and extremely deep caries and positive response to sensibility testing. Diagram illustrating suggested clinical pathway and treatment options based on clinical findings. The suggested pathway is based on ESE position statement on the management of deep caries and exposed pulp (2), augmented with authors perspective, *Caries extend into the pulpal quarter of the dentine, but with a well-defined zone of radiopaque dentine separating the infected demineralized dentine from the pulp. **Caries involve the entire thickness of the dentine, without a radiopaque zone separating the lesion from the pulp. # bleeding can be controlled within 5 min, ## bleeding controlled within 5 min and no sign of necrosis in any canal. HP, healthy pulp; IDPC, indirect pulp capping; RP, reversible pulpitis; IRP, irreversible pulpitis.

TABLE 2 | Comparative analysis of clinical and patient related factor for root canal treatment and vital pulp treatment in permanent teeth.

Factors	Root canal treatment vs. vital pulp treatment	Supportive evidence
Aerosol generation	RCT generate more bacterial aerosols compared to pulpotomy	(44, 45)
Pain relief	RCT results in significantly more postoperative pain compared to pulpotomy Pain relief in pulpotomy is comparable to RCT	(46–48)
Success rate	Success rate (clinical and radiographic) at 1, 2, and 5 years for pulpotomy is comparable to RCT	(47, 49, 50)
Treatment time	Pulpotomy requires significantly less treatment time compared to RCT	(48, 49)
Cost-effectiveness	Pulpotomy is more cost-effective than RCT Pulp capping is cost-effective compared to RCT in subjects aged below 40 years Direct pulp capping with MTA is more cost-effective than calcium hydroxide Selective caries removal is more cost-effective than non-selective caries removal in maintaining pulp vitality	(49, 51–53)

for pulpitis treatment. Although CSCs has greatly contributed to the current success of VPTs, these materials are not without limitations. The anti-inflammatory and antibacterial properties reported for these materials are controversial (54). The materials, although biocompatible, but contain heavy metals the long term effect of it is not known (55). Once placed these materials are not resorbable and therefore limit the

chance of true regeneration and replacement of lost pulp tissue. Future materials that control microbial contamination and treat inflammation and at the same time allow for the regeneration of damaged pulp are required. In this regard development of functionalized scaffolds that can act as effective carriers for biological molecules, which could target inflammation and/or infection and promote the release of

dentine bound growth factors and chemokines is promising (56, 57).

There is also a lack of consensus regarding the most appropriate way to manage deep caries and pulpal exposure, with recent questionnaire-based research highlighting differences in attitude influences by teaching, geographical location and dentists age, which impact clinical decision-making (58). Indeed, there is much work to be done to educate dentists, patients and other stakeholders about the advantages of VPT and its increased role in practise (59) (Table 2). Although it is challenging to alter the traditions of patient management particularly to older more experienced dentists the recent promotion of ESE-supported VPT awareness campaigns are a step in the right direction (<https://www.e-s-e.eu/news/ese-awareness-campaign-on-vital-pulp-tre>).

CONCLUSION

Preservation of the vital pulp is crucial for long term tooth survival. Although RCT is highly successful in managing teeth

with irreversible pulpitis, its complexity and the cost could be prohibitive particularly in the situation where resources are sparse. Within the era of minimally-invasive medicine and surgery the need for Dentistry to embrace VPT is already strong; however, in light of recent calls to embrace simplicity and reduce chair time in the COVID-19 environment the opportunities for development of VPT have never been more obvious.

DATA AVAILABILITY STATEMENT

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding author/s.

AUTHOR CONTRIBUTIONS

IK and HD contributed equally to the conception, design and drafting and editing of the manuscript. The authors agreed to be accountable for the content of the work. Both authors contributed to the article and approved the submitted version.

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Conflict of Interest: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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